Proc. of the 2017 IEEE Region 10 Conference (TENCON), Malaysia, November 5-8, 2017

Comparison of Shepherding Control Behaviors

Kaoru Fujioka
International College of Arts and Sciences, Fukuoka Women's University
1-1-1 Kasumigaoka, Higashi-ku, Fukuoka 813-8529, Japan
Email: kaoru@fwu.ac.jp

***Abstract*—Self-organized flocking behavior is often seen in nature in the form of flocks of sheep, herds of cow, fish schools, and swarms of insects. The shepherding problem is concerned with the control of such a group by a small number of guides and has useful applications. The present paper focuses on two unrelated control methods and the similarities between them. Based on these two control methods, we introduce a new hybrid control method. The effectiveness of all three control methods is considered based on success rate, speed, and dispersion of the group. The trajectories of the shepherds are also shown. The results for our proposed method help to improve understanding of effective control methods.**

I. Introduction

In nature, we see self-organized flocking behavior, and this behavior has been studied and simulated by many researchers, such as in [1]. The effective driving and control of such a group by a small number of guides is the objective of the shepherding problem which considers the movement of shepherds when steering sheep to a target position.

Using actual Global Positioning System (GPS) data for shepherds and sheep, a control method using a single shepherd is demonstrated and simulated in [2]. The motion of shepherds is represented by adaptive switching between collecting agents and driving agents, depending on the dispersion of agents. In this paper, we refer to the control of flocks as global center of mass (GCM)-targeting control.

In [3], shepherding behaviors in a complicated field are analyzed. The shepherding problem with multiple shepherds is considered in [4]. A control method called V-formation control is introduced in which a shepherd traces a V-shaped notch toward the target position until the simulation stops in [5], and this method is compared with other methods using a single shepherd, in terms of success rate, speed, and dispersion. The success rate in the V-formation control is higher than in the GCM-targeting control method, though the V-formation control method requires more time to guide.

In this paper, we focus on the collective behavior in GCM-targeting control and regular motion in V-formation control, and then introduce a new hybrid control method. The effectiveness (success rate) is plotted, and the trajectories of the shepherds are illustrated for these methods.

This paper is organized as follows. The details of our shepherding model are presented in Section II. Then, the results of computer simulations are shown in Section III. Section IV concludes the paper.

II. Shepherding Model

First, we illustrate the basic configuration of our model. In a square field with sides of 250 meters, $N = 100$ agents (sheep) are randomly distributed in the center of the field over an area of 50×50 meters at the beginning of the simulation as shown in Figure 1. The task of the shepherd, which initially locates at position $(125, 0)$, is to guide the agents to the target position $(125, 250)$. A simulation is regarded as successful if the GCM of the agents, which is the center of all agents (see Figure 1), is within 5 meters of the target position within 1000 steps.

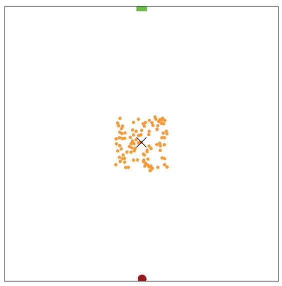


Fig. 1: Screen shot of the agents (orange circle), shepherd (red circle), GCM of the agents (x mark), and target position (green rectangle) at the beginning of the simulation.

We define the behavior of agents based on information from previous studies [2]. Each agent decides its next position from its movement vector $\boldsymbol{R}$ which is determined by the following five unit vectors of length 1 such that

$$\boldsymbol{R} = \rho_d \hat{R}_d + \rho_L \hat{R}_L + \rho_r \hat{R}_r + \rho_i \hat{R}_i + \rho_e \hat{R}_e, \qquad (1)$$

where

- $\hat{R}_d$ is the force to get away from a shepherd within the detection distance $d_{\text{detect}} = 65$.
- $\hat{R}_L$ is the cohesive power for the center of the n nearest agents.
- $\hat{R}_r$ is the repulsion force if other agents are within the repulsion distance $d_r = 2$.
- $\hat{R}_i$ is the inertial force to remain at the current position.
- $\hat{R}_e$ is the noise or random element in the agent's trajectory.

The values for the parameters in (1) are $\rho_d = 1$, $\rho_L = 1.05$, $\rho_r = 2$, $\rho_p = 0.5$, $\rho_e = 0.3$ based on previous studies, and the speed of agents is 1 meter per time step. In the above definition of $\hat{R}_L$, we refer to n as the *number of neighbors*.

978-1-5090-1134-6/17/$31.00 ©2017 IEEE

A shepherd moves toward the designated position with speed 1.5 meters per time step unless an agent exists within $3d_r$, in which case the shepherd approaches with speed $0.3d_r = 0.6$ meters per time step. Algorithms for a shepherd to control a crowd have been proposed. In this paper, we focus on the GCM-targeting control and V-formation control methods. GCM-targeting control was proposed based on actual shepherd behavior [2], in which a shepherd switches between a driving movement and a collecting movement. The driving movement in GCM-targeting control, where a shepherd moves behind the GCM toward the target position, will work well only when the agents are cohesive. On the other hand, V-formation control shows a higher success rate when the agents are dispersed. Therefore, as a starting point for our study, we focus on the collecting movement in GCM-targeting control, before including elements of V-formation control. In the following subsections, we define Collecting control and V-formation control. Furthermore, based on the two control methods, we propose a new control method, called *Collect via Center* (*CvC*) *control*.

A. Collecting control

A shepherd moves to steer the furthest agent from the GCM into the flock by moving toward the collecting position P_{collect}, which is located d_{over} behind the furthest agent. The furthest agent satisfies the condition that the angle θ_1 between the agent and the target position with respect to the GCM is greater than 90 degrees. Thus, no agent satisfying $\theta_1 \leq 90$ is called the furthest agent even if the distance between the GCM and the agent is greater than those of all other agents. We note that if there is no restriction on the angle θ_1 for the furthest sheep, then the shepherd is unable to guide the GCM to the target position from the preliminary experiment.

We set d_{over} as $5d_r$, which is different from the initial value d_r in [2], in order to equalize the distance from the GCM with P_{right}, P_{center}, P_{left} in the V-formation control in the next subsection.

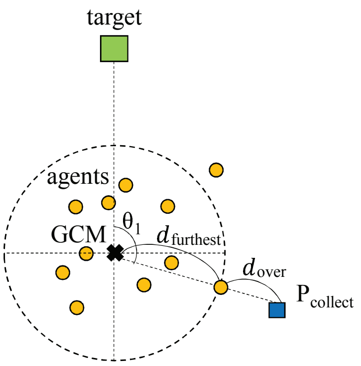


Fig. 2: Collecting position P_{collect} in Collecting control.

B. V-formation control

A shepherd traces a V-shaped notch toward the target position at all times. After starting, a shepherd randomly turns to move toward one of the positions $P_{\text{right}}, P_{\text{center}}$, or P_{left} (Figure 3), which are located $d_{\text{over}} = 5d_r$ behind the furthest agent. From the previous study [5], we set the angle between P_{right} (or P_{left}) and P_{center} with respect to the GCM as $\theta = 60$ degrees, which has shown a high success rate in previous studies. In a similar way to Collecting control, the furthest agent satisfies the condition that the angle θ_1 is greater than 90 degrees.

The shepherd goes toward P_{center}, P_{right}, P_{center}, then P_{left} in turn. If the next target position is located outside of the field, then the shepherd skips that position. The shepherd repeats this process until the simulation stops.

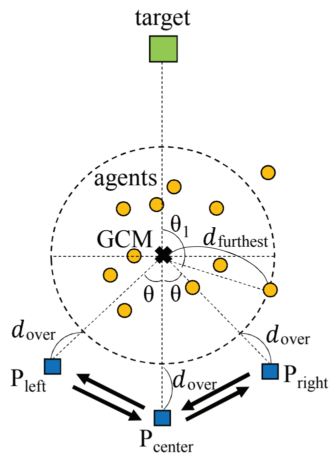


Fig. 3: Three positions, P_{right}, P_{left}, P_{center}, in V-formation control.

C. Collecting via Center (CvC) control

We propose a hybrid of the Collecting control and V-formation control methods, called *Collecting via Center* (*CvC*) *control* as follows.

- If a shepherd and the collecting position P_{collect} are located on the same side of the crowd as position P_{center}, then the shepherd moves directly to position P_{collect} (see Figure 4 (left)).
- Otherwise the shepherd moves to position P_{center} (see Figure 4 (right)).

III. Results

We show the success rate, speed, and dispersion of the flock for the three control methods in Subsection III-A. The trajectories of the shepherd in the three control methods are shown in Subsection III-B.

A. Control Effectiveness

Figures 5, 6, and 7 show the success rate, average number of steps to success, and average dispersion over 100 experiments, respectively, for the three control methods defined in Section II. The dispersion is defined as

$$\frac{d_1^2 + d_2^2 + \cdots + d_{100}^2}{100},$$

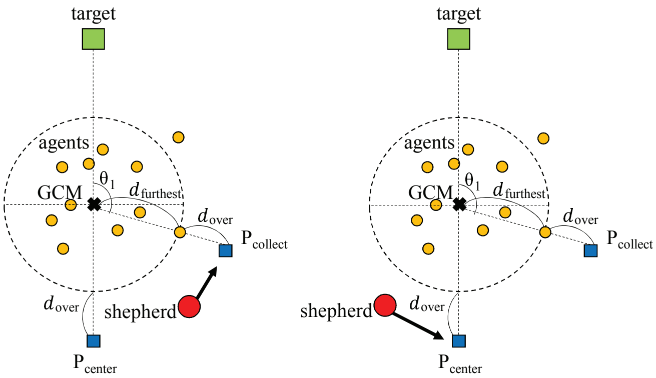


Fig. 4: Shepherd moving in CvC control.

where d_i is the distance between the GCM and agent i ($1 \leq i \leq 100$) at the end of the simulation.

We change the value of the number of neighbors n from 1 to 50. If n is greater than 50, the flock will always move together without scattering from the definition of the vector $\hat{R}_L$.

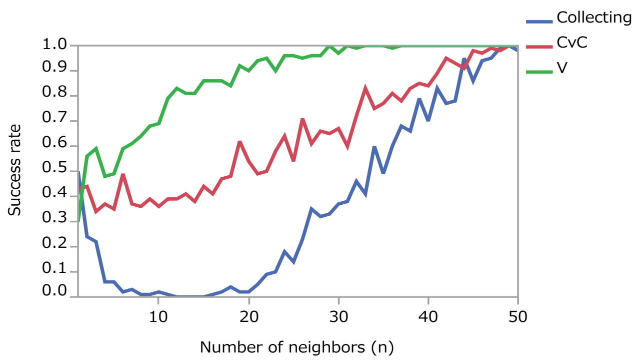


Fig. 5: Success rate for the three control methods.

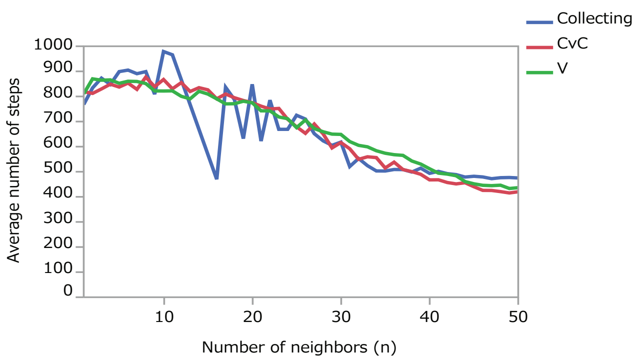


Fig. 6: Average number of steps for the three control methods (not including failures).

From Figure 5, the Collecting control method had a higher success rate than the CvC control method, which in turn had a higher success rate than the V-formation control method for most values of n. The success rate tends to increase with the number of neighbors n. However, for n less than 10, the success rate tends to decrease with increasing n especially for the Collecting control method. Actually, the success rate of the Collecting control method is 50 percent for $n = 1$ and 2 percent for $n = 10$, while for the V-formation control method it is 30 percent for $n = 1$ and 69 percent for $n = 10$.

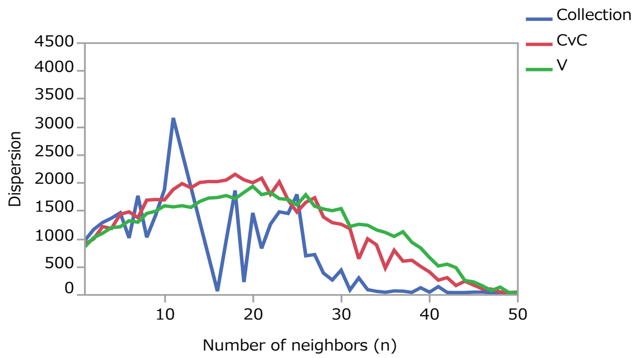


Fig. 7: Average dispersion for the three control methods (not including failures).

Figure 6 shows the average number of steps until success. If all 100 simulations are unsuccessful, then no point is plotted. Together with the result of the success rate in Figure 5, the scatter plot for the Collecting control method between 5 to 20 is based on fewer than 10 results or is not displayed. Then, generally speaking, the average number of steps decreases with an increasing number of neighbors n, and the difference between the three control methods is small, except for $10 < n < 20$.

Figure 7 shows the average dispersion for a successful simulation. In a similar way to Figure 6, if all 100 simulations are unsuccessful, then no corresponding point is plotted. In contrast to Figure 5, Collecting control, CvC control, and V-formation control show increasing dispersion in this order if we ignore the points for low success rates.

Figure 8 shows the changes in the dispersion for the three control methods, for 1 to 1000 steps for n = 1, 10, 20, 30, 40, and 50. Each line shows the average dispersion at each step over 100 experiments and includes both successful and unsuccessful simulations.

When we focus on the three lines with the same n (plotted with the same color), the Collecting control, CvC control, and V-formation control show decreasing dispersion in this order for each step. Regardless of the control method, for $n = 50$, the dispersion is stable and is less than 80 after 100 steps. Following $n = 50$, the dispersion for $n = 1$ and $n = 40$ is lower than that for other n.

B. *Trajectories*

We show the trajectories of the shepherd (purple line) and the GCM (black line) for $n = 10, 20, 30,$ and 40 in Figures 9 to 12. The positions of the agents and the shepherd are also plotted for the last step.

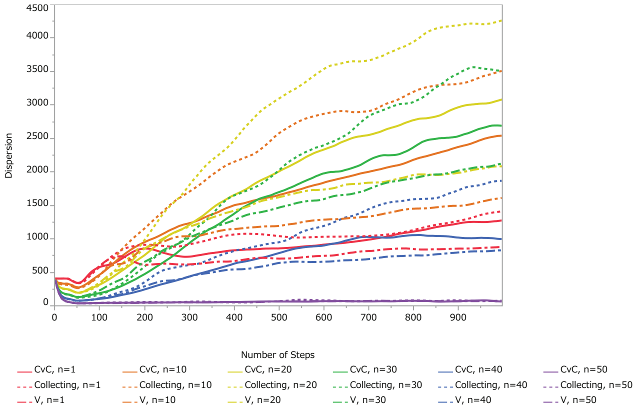
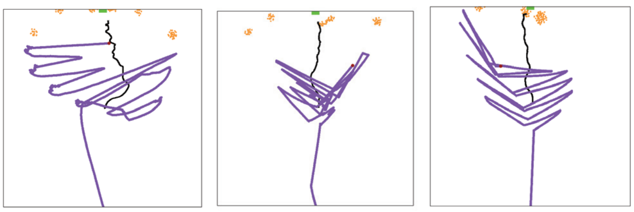


Fig. 8: Dispersion of the three control methods for different numbers of steps (failures are included).

In Collecting control, a shepherd is only required to chase the furthest agent, but the shepherd can be seen to regularly move from side to side and the three trajectories are quite similar for $n = 40$ in Figures 12a to 12c. The trajectories of the GCM are regularly controlled, especially in V-formation control for $n = 40$.

As the number of neighbors n decreases, the change in the shepherd's trajectory becomes larger and agents (orange circles) are more dispersed at the end of the simulation. In V-formation control and CvC control, the shepherd traces a V-shaped notch toward the GCM regardless of the value of n. In contrast, the shepherd moves side to side directly without detour in Collecting control.

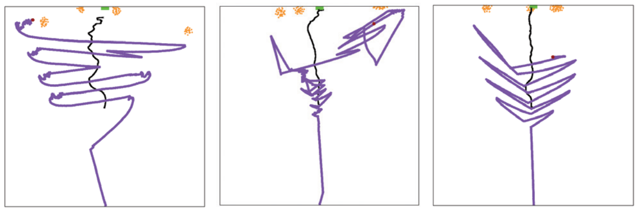


(a) Collecting control, trial is unsuccessful. (b) CvC control, trial is unsuccessful. (c) V-formation control, trial is unsuccessful.

Fig. 9: Trajectories for $n = 10$.

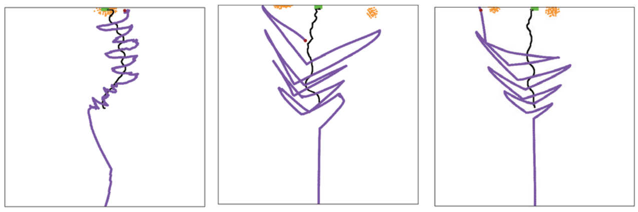
IV. Conclusion

In this paper, we introduced the CvC control method based on the V-formation control and Collecting control methods, and then compared effectiveness between the three methods in terms of success rate, average number of steps until success, and dispersion. The trajectories of the shepherds in these control methods were also presented. Although V-formation control and Collecting control are defined independently, similar patterns in the trajectory of the shepherd were found. The values of the success rate, dispersion, and trajectory, for the



(a) Collecting control, trial is unsuccessful. (b) CvC control, trial is successful. (c) V-formation control, trial is successful.

Fig. 10: Trajectories for $n = 20$.



(a) Collecting control, trial is successful. (b) CvC control, trial is successful. (c) V-formation control, trial is successful.

Fig. 11: Trajectories for $n = 30$.

(a) Collecting control, trial is successful. (b) CvC control, trial is successful. (c) V-formation control, trial is successful.

Fig. 12: Trajectories for $n = 40$.

CvC control method are, in most cases, between those of the V-formation control and Collecting control methods.

Our results help to improve understanding of the behavior of collected agents and thus can help improve understanding of effective control methods.

Acknowledgment

This work is supported in part by JSPS KAKENHI Grant Number 15K21308.

References

[1] Reynolds, Craig W., *Flocks, herds and schools: A distributed behavioral model*, SIGGRAPH Comput. Graph., Vol. 21, No. 4, pp. 25-34, 1987.

[2] Strömbom, Daniel and Mann, Richard P. and Wilson, Alan M. and Hailes, Stephen and Morton, Jennifer A. and Sumpter, David J. T. and King, Andrew J., *Solving the shepherding problem: heuristics for herding autonomous, interacting agents*, J. R. Soc. Interface, Vol. 11, No. 100, 2014.

[3] Lien, Jyh-Ming and Bayazit, Burchan O. and Sowell, Ross T. and Rodriguez, Samuel and Amato, Nancy M., *Shepherding behaviors*, In Proc. IEEE ICRA'04, pp. 4159-4164, 2004.

[4] Lien, Jyh-Ming and Rodriguez, Samuel and Malric, Jean-Phillipe and Amato, Nancy M., *Shepherding behaviors with multiple shepherds*, In Proc. IEEE ICRA'05, pp. 3402-3407, 2005.

[5] Fujioka, Kaoru and Hayashi, Sakiko, *Effective shepherding behaviours using multi-agent systems*, In Proc. 2016 IEEE Region 10 Conference (TENCON), pp. 3183-3186, 2016.